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Meso-structures evolution rules of coal fracture with the computerized tomography scanning method

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ABSTRACT

In order to observe the meso-structure and fracture process of coal interior, the computerized tomography (CT) scanning experimental system was developed. This system includes the nonmetal cylinder shell, loading head, strain test equipment, hydraulic pump and vacuum pump, which can scan coal or rock samples with or without gas under uniaxial and triaxial load. The uniaxial compression experiments of coal were done and CT images were obtained at different stress level. The results show that the raw coal is a kind of heterogeneous material and the internal distribution of density is inhomogeneous. The cracks are uneven and their directions are random. During the loading process the inner structures of coal changed. The density of the coal increases at the beginning of load and decreases with the increment of stress. The fractures of coal occur mainly between the skeleton and matrix and on the weak region of the skeleton. Moreover, CT images from the experiments were used to reconstruct 3D images of coal under different stress states. The deformation and fracture process can be observed obviously. These investigations can provide theoretical foundations for understanding of fracture mechanism of coal.

1. Introduction

Coal–rock dynamic disasters, such as coal and gas outburst and bump pressure, pose a serious threat in coal mines. Therefore, investigations on coal–rock deformation and fracture law under compression are of profound significance to reveal both coal–rock dynamic disaster mechanism and its deformation and fracture mechanism. Coal–rock medium is a kind of porous medium with well-developed joint and crack. It belongs to a typical heterogeneous multi-phase composite material [1]. Because of its structural complexity, its mechanical properties are also very complicated. At present, the deformation and fracture process of coal–rock material is mostly investigated based on macro view or in respect of the meso-structure deformation and fracture characteristics on the coal–rock surface. However, few investigations were performed on the crack change and meso-structure within coal–rock under compression. Analytical techniques commonly applied to the study of rock microstructure are restricted to two-dimensions because of the equipment used: optical and/or scanning electron microscopy [2–4]. One of the earliest, and most well-known, studies of crystal size distributions in igneous rocks was of the Makaopuhi Lava Lake, Hawaii [4,5]. Wang utilized long-distance telescope of high power dynamically observed the deformation and fracture process of coal containing gas under uniaxial compression, similarly finding that coal deformation and fracture is discontinuous and uneven [6]. Yang et al. [7] used CT scanning method to investigate the initial meso-structure damage properties and damage propagation of coal under uniaxial compression. Ge et al. [8] conducted CT dynamic

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experiments on triaxial meso-structure damage evolution law of coal–rock, obtaining clear CT photos during all stages, such as micro-pore being compressed closely – microcrack initiation – bifurcation – development – fracture – damage – unloading in the coal–rock under different loads. KawaKata et al. observed the crack of granite grow under triaxial compression with X-ray CT scanning system [9]. Yin et al. [10] conducted CT experiments on the damage evolution of coal–rock under uniaxial compression, revealing the damage evolution law on coal–rock under uniaxial compression during stress stages. Mazumder et al. [11] made use of CT technique researching the cleat pores of coal sample and their spacing. Therefore, industrial CT method can be used to observe the internal structure change of coal–rock in its deformation and fracture dynamic process [12]. Nakashima and Kamiya [13] developed a mathematic program to obtain the pore connectivity and anisotropic tortuosity porosity of rock by CT images. Karacan studied the gas adsorption and transport in coal, and spatial distribution of adsorption in coal [14,15]. In this paper, state-of-the-art industrial CT scanning experiment system ACTIS (300–320KV/225KV) CT is employed to research the deformation and fracture of coal samples under uniaxial compression. The system has resolution of up to 15 μm for the tested samples at a diameter of 25 mm. This system lays experimental foundation for revealing the damage and deformation of coal–rock under uniaxial compression.

2. CT scanning experiment system

Based on industrial CT scanning system, nonmetal loading cylinder which can permit X-ray to penetrate is established, and long-distance loading experiment device for coal–rock containing gas for CT scanning system is designed. The experiment system consists of industrial CT scanning system, coal–rock loading system and strain test system, etc., as shown in Fig. 1.

2.1. Industrial CT system and its characteristic parameters

The radiographic source used for industrial CT system mainly comprises X-ray source and γ-ray source. Among them, X-ray source is commonly used.

ACTIS(300–320KV/225KV)CT system produced in USA is used in this experiment. X-ray with different energies is selected, which can precisely and correctly reproduce the 3D structure of an object and quantitatively output the physical and mechanical properties of the object, such as defect, crack, the location, size and density change and size of the skeleton, etc. Its test principle is shown in Fig. 2.

Main performance and parameters of ACTIS (300–320KV/225KV)CT experiment equipment include: (1) two separate X-ray sources; (2) three options for image enhancer: at a diameter of 215 mm, 160 mm or 120 mm; spatial resolution of 7.0/6.2/5.6 lp/mm; (3) CCD camera: resolution of 1024 × 1024; frame rate of 15 Hz at full resolution or 30 Hz at 2 × 2 binning; (4) slices at a width of: 0.4 –10.0 mm for 320 kV standard radiographic source (adjustable); 10 μm–1.0 mm for 225 kV micro-focus radiographic source; (5) CT spatial resolution and scanning time are related to scanned objects, as shown in Table 1. The relationship between CT density resolution and size: 0.2% resolution is reached in a region at a diameter of 10 mm; (6) The system is equipped with two independent rotating platforms and slice positioning axle that can achieve transverse or longitudinal rock core testing.

2.2. Coal–rock loading system and strain test system

The self-developed loading system consists mainly of loading cylinder, upper and lower loading head, strain test equipment, hydraulic pump and vacuum pump, as shown in Fig. 3. The loading cylinder is made of nonmetal polymer and the

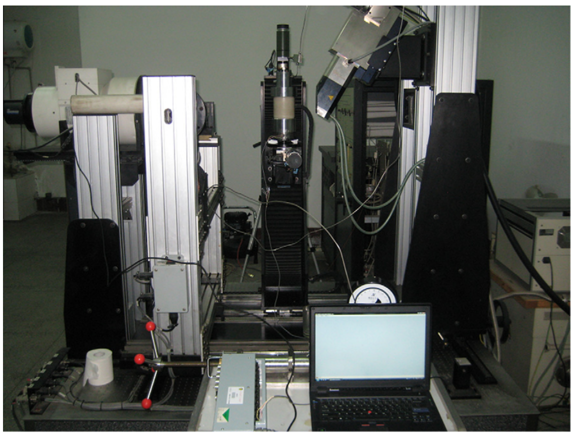

Fig. 1. Photograph of CT scanning and EME acquisition experimental system.